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Testing a Structural Equation Model of Language-based Cognitive Fitness with Longitudinal Data

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Abstract

Development of language is taken for granted by most. Problems with language development can result in stress for the individual and family; there is a challenge in that the contemporary education system assumes children have appropriate skills when they begin school. The purpose of the study is to further test a theoretical model of language readiness known as language-based cognitive fitness, which includes measures associated with structural concepts of language involving verbal reasoning ability, visual synthesis, and active analysis that explained 91% of the variance in achievement, with longitudinal data. The sample includes children from a private school who received an extensive battery of tests at admission and annually thereafter. Scores from 11cognitive measures were used in a structural equation modeling framework to test the model derived from cross-sectional data with longitudinal data over three time points. Results from this longitudinal analysis demonstrated language-based cognitive fitness to be an interaction of verbal reasoning abilities, visual synthesis, and active analysis depending on the time period. There is a hint of hierarchical structure but it is a secondary consideration to the core model. Implications for positive social change include an improved understanding of the language structures responsible for language deficits and how these relate to overall cognitive fitness; and, the potential for interventions crafted to help children more quickly make up language deficits.

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Keywords: language; language fitness; cognitive fitness; language taxonomy; verbal reasoning; visual synthesis, active analysis; verbal; visual; modelling language; exploratory factor analysis; structural equation modeling; longitudinal study

1. Introduction

Children with delays in language processing and acquisition are at risk for learning difficulties across academic subjects including reading and mathematics (Cowan et al., 2005). A disorder of language has negative implications for psychosocial development of affected children and youth, including early school dropout and psychiatric disorders as a consequence of chronic experience of school failure (Schulte-Körne et al., 2010; Schulte-Körne & Bruder 2011). Researchers

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have demonstrated that language disabilities persist into adulthood for 40-50% of those affected (Schulte-Körne et al., 2010). A study by Moxley-Paquette, Burkholder, and Constantinidis (2013) demonstrated specific precursor skills in verbal reasoning ability, visual synthesis, and active analysis important to achievement using cross sectional data. Additional review of longitudinal data was recommended to further validate and strengthen the 3-factor language-based cognitive fitness model. Longitudinal validation can better elucidate the underlying constructs of language and their interactions; such elucidation is important for understanding the language-achievement connection and can provide practical insight into how to respond to specific challenges in language development.

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2. Review of the Literature

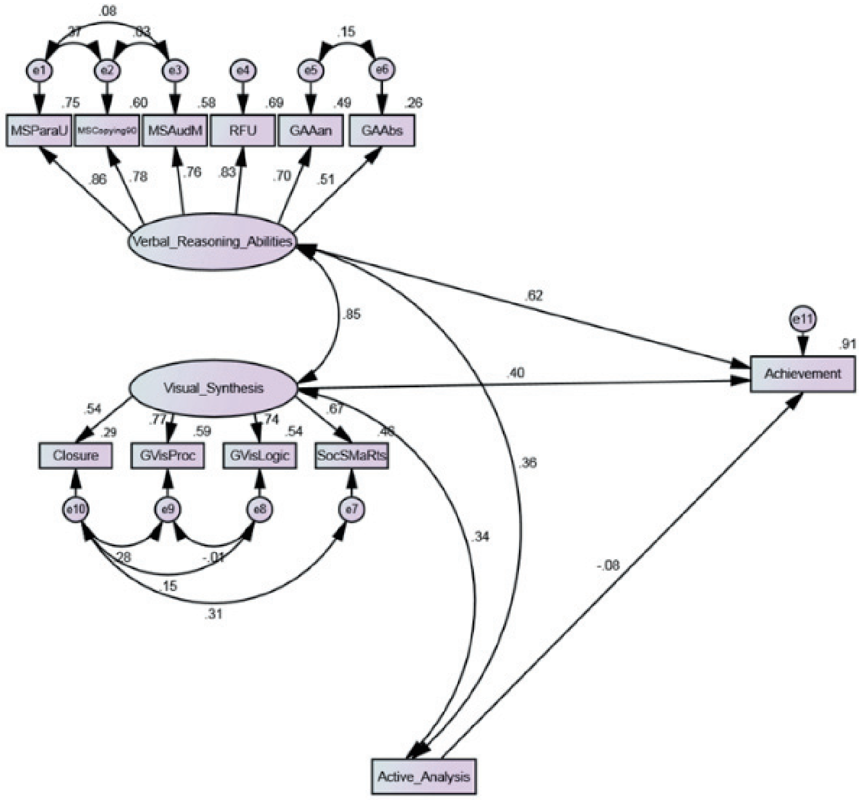
Cognitive fitness is the state of our ability to carry out cognitive tasks with vigour and alertness, to learn, and to adapt efficiently to all circumstances (Gläscher, et al. 2009, 2010; Jung & Haier, 2007; Moxley-Paquette & Burkholder, 2014; Oberauer et al., 2003; Salthouse, 2005; Shelton, et al. 2010). The importance of cognitive fitness to the *development of language* has been broadly supported by foundational research from Goldstein (1936, 1946), Goldstein and Scheere (1941), Hannaford (1995), Head (1920, 1923), Luria (1973), and Vygotsky (1962), and from contemporary neurobiological researchers including Damasio (1989), Kemp and Tenenbaum (2009), Semrud-Clikeman (2010), Tranel, Rudrauf, Vianna, and Damasio (2008), and Wasserman and Young (2010).

A 3-factor model of language-based cognitive fitness defined by Moxley-Paquette and Burkholder (2014) supported previous work that demonstrated receptive and expressive language involved a multifaceted, interrelated, and multilevel taxonomic model supported by specific language acquisition abilities (Allen, Bruss, & Damasio, 2004; Buehner et al., 2006; Colom, Jung, & Haier, 2007; Cowan et al., 2005; Gläscher, Rudraulf, et al., 2010; Gläscher, Tranel, et al., 2005; Hannaford, 1995; Jung & Haier, 2007; Levine, 2002; Luria, 1973; Menzinich, 2001; Neubauer & Fink, 2009; Oberauer, et al., 2003; Inhelder & Piaget, 1958; Piaget, 1926; Salthouse, 2005; Semrud-Clikeman, 2005; Turken et al., 2008; Vygotsky, 1929). It drew upon literature from research beyond the classic and generally accepted Broca-Wernicke-Lichtheim language model (Shalom & Poeppel, 2008) including literature pertaining to mismatch negativity MMN-vMMN associated with memory trace formation (Garrido et al., 2009; Kujala et al., 2007; Näätänen, 2000; Näätänen, 2007); Näätänen et al., 2011; Pulvermüller et al., 2008; Pulvermüller & Shtyrov, 2003; Sussman, 2007; van Zuijen et al., 2006; Winkler & Czigler, 2011), the interplay of cognitive abilities (Buehner et al., 2006), functional language organization (Shalom & Poeppel, 2008), and the physical anatomy of language using neuroimaging techniques (Catani, 2009; Price, 2012). The emergent model from Moxley-Paquette and Burkholder (2014) was not hierarchical in structure as anticipated; rather, the model suggested an interactional approach to understanding language development. This interactional model could not, however, be tested using entirely cross-sectional data.

2.1. The Emergent 3-Factor Relational Model of Language-based Cognitive Fitness

The empirical model (Moxley-Paquette & Burkholder, 2014) suggests that verbal reasoning ability, visual synthesis, and active analysis are important to predicting achievement. The interaction among constructs was demonstrated by strong covariance between Verbal Reasoning Ability and Visual Synthesis and, to a lesser degree, between both Verbal Reasoning Ability and Visual Synthesis and Active Analysis. There is support in the literature for verbal and visual construct connection at the earliest stages of memory trace formation during a temporal window of integration (TWI) and specifically within literature pertaining to mismatch negativity MMN-vMMN associated with memory trace formation (Garrido et al., 2009; Kujala et al., 2007; Näätänen, 2000; Näätänen, 2007); Näätänen et al., 2011; Pulvermüller et al., 2008; Pulvermüller & Shtyrov, 2003; Sussman, 2007; van Zuijen et al., 2006; Winkler & Czigler, 2011), thus supporting the interplay of cognitive abilities (Buehner et al., 2006). This structure diverges from the originally proposed hierarchical structure, based on theory in the literature, in which verbal reasoning precedes visual synthesis and visual synthesis precedes active analysis in language development.

Figure 1
An Interactive Model for Language-based Cognitive Fitness



Note: – the squares represent the 11 test items; the ovals represent the factors one and two with multiple variables; the rectangle represents factor three represented by one variable; the circles represent the error terms; the arcs represent covariances between variables and between factors; the arrows represent pathways of influence; and, the numbers over the pathways represent the strength of the path relationship. PU = paragraph understanding; MSC = Copying; AM = Short term auditory memory; RFU = Reading for Understanding; GAAan = Gibson Auditory Analysis (analysis); Closure = Closure Speed; GVisProc = Gibson Visual Processing; GVisLogic = Gibson Logic and Reasoning; SocSMaRts = Social Comprehension; XoL = GDRAAT Crossing-Out-Letters; KMWK= Achievement = the average of Woodcock and KeyMath percentages; VRA= Verbal Reasoning Abililty; VS= Visual Synthesis; AA=Active Analysis (equates to a single variable XoL. Additionally, 1 = Baseline; 2 = End of Year 1; 3 = End of Year 2.

In the interactive model that emerged each of the three latent factors predicted achievement: *Verbal Reasoning Abilities* ($\beta = .62$, $p = .00$); *Visual Synthesis* ($\beta = .40$, p=.00); and *Active Analysis* ($\beta = -.09$, $p = .02$). The three latent factors explained 91% of the variance in achievement.

3. Research

3.1. Purpose and Nature of the Study

The purpose of the study was to use longitudinal data to further test the 3-factor model of language-based cognitive fitness using three points in time (baseline, end of Year 1, and end of Year 2). Structural equation modelling (SEM) is an advanced statistical modelling technique suitable for exploratory testing of proposed models as well as for confirmatory analysis (Bentler, 1990; Burkholder & Harlow, 2003; L-t Hu & Bentler, 1999). Other researchers have successfully explored language development using SEM (for example, Gläscher, et al. 2009, 2010; Jung & Haier, 2007; Oberauer et al., 2003; Salthouse, 2005; Shelton, et al. 2010). Given that the model initially proposed (Moxely-Paquette, Burkholder, & Constantinidis, 2013) represented a linear stages-of-development model, and the best fitting model using baseline cross-sectional data represented more of an interactionist model, we sought to test both types of models using longitudinal data; longitudinal modeling is strongly recommended for helping to establish true causal pathways (Burkholder & Harlow, 2003).

3.2. Target Population, Sample, and Sampling Procedures

The target population for this study included students attending private schools who represent the spectrum of challenged, average, and gifted achievement for their ages. The participants providing data were from a K-12 private school. Participant ages at baseline ranged from 5 to 18 years (M = 11.2 to 12.9, SD = 2.7). Males represented 72% of the students. In terms of cognitive ability, 57% of students (n = 34) had a challenged cognitive profile, 27% (n = 16) had an average profile, and 16% (n=10) had a gifted cognitive profile at baseline. At the third assessment, 35% (n = 21) had a challenged cognitive profile, 48% (n = 29) had an average profile, and 16% (n = 10) had a gifted profile. All students were tested for ability and achievement at time of entry and at the end of each academic year. The purpose of this testing was to establish entry levels of academic achievement and neurocognitive profiles of strengths and weaknesses; this allowed for tailored academic programming fit to the needs of individual students; end of year testing provided indication of progress. All tests were administered by the school's educators to students as part of normal administrative process. Informed consent of the original data collection was included as part of the school's administrative procedures. Permission to use this data for the purposes of research was obtained by the school as part of the yearly student registration process. The Walden University institutional review board approved the study.

3.3. Operationalization of Study Variables

Key information provided for each measure includes a) name of the instrument and b) ability or attribute measured. In most cases, the raw score is used and transformed into a percentage correct to standardize measures among variables; the exception is the Reading For Understanding (RFU) test for which a level and percentage correct is assigned). Higher scores for all tests represent higher ability. Correlation with other tests was used as evidence of validity.

3.3.1. Measures

Verbal Reasoning Ability included 6 measures. The *GCTB Auditory Analysis* blending and segmenting subtests measure the individual's ability to blend and segment sounds given audibly (Gibson, 1999); it is a form of repetition. *Gibson's Auditory Analysis* (analysis) subtest of the Gibson Cognitive Test Battery (GCTB) measures the individual's ability to *hear and analyze* speech sound within a spoken pattern (Gibson, 1999). The *Group Diagnostic Reading Aptitude and Achievement* Tests (GDRAAT) *Auditory Letter Memory* subtest measures auditory-based short term memory formation and recall (Munroe & Sherman, 1966). The *GDRAAT Paragraph Understanding* measures more literal understanding of paragraph content demonstrating deductive reasoning. *Reading for Understanding* (RFU) measures inferential understanding of paragraph content (Kemp, 1982). The *GDRAAT Copying Test* measures an individual's ease of handwriting, or motor fluency under time constraint.

Visual Synthesis included 4 measures. The *GCTB Visual Processing* subtest measures the ability to picture, manipulate, organize, comprehend, and think with visual information (Gibson, 1999). The *Thurstone Closure Speed Test (TCST)* measures an individual's ability to visualize parts and wholes of pictures, to construct a gestalt from visual features, and close in on the name of an object (Thurstone & Jeffrey, 1984). The *Social SMaRts Test* tests the individual's ability to critically evaluate a picture of a social situation, plan a response, organize inner speech, and then verbalize this response. The *GCTB Logic and Reasoning* subtest measures the individual's ability for conceptual pattern analysis using visual stimuli.

Active Analysis included a single measure, the *GDRAAT Crossing-Out-Letters* test, which measures the ability to selectively attend to task, discriminate the target symbol, and check for accuracy.

For *Achievement*, the two primary dependent measures of achievement (reading and mathematics) were combined into a single variable. The *Woodcock Reading Mastery* (WRMT-R) and *Key Math* (KMT-R) test protocols are widely accepted in psychoeducational circles with strong evidence of validity (Murray-Ward, 2012) and reliability (Beck, 2012). These two composite measures were combined by averaging the resulting total scores to define achievement.

3.4. Procedure

Data were screened and cleaned and tested for multivariate assumptions (Tabachnick & Fidell, 2007). Data met assumptions of multivariate normality, linearity, and heteroscedasticity of the variables. There were 151 cases with complete data for analysis for the baseline sample, 84 cases with complete data for Time 2 (end of Year 1), and 60 cases with complete data for analysis in Time 3 (end of Year 2). SPSS Version 21 and SPSS AMOS 19 were used for the analyses. Model fit was judged using fit indices including chi square statistic (χ^2) (non-significant probability value indicates an excellent fit to the data); χ^2 to the degrees of freedom ratio (ideally less than 2.0); root mean square error of approximation (RMSEA) of less than .10; and comparative fit Index (CFI) greater than .95 (Tabachnick & Fidel 2007; Bentler, 1990; Hu & Bentler, 1999).

Two different models were hypothesized to explain the data. The first model represents a longitudinal variation on the original interactive model (Figure 1). Model 1 includes *Achievement* measured at the end of Year 2 (Time 3) regressed onto baseline values of *Verbal Reasoning Ability, Visual Synthesis,* and *Active Analysis* (assessed at baseline). The second model represents a version of the hierarchical model that is similar to the hierarchical model proposed by Moxley-Paquette, Burkholder, and Constantinidis (2013). Model 2 assumes a more linear approach to cognitive fitness, with *Verbal Reasoning Ability* a co-requisite with *Visual Synthesis*, both *Verbal Reasoning Ability* and *Visual Synthesis* a prerequisite for development of *Active Analysis* abilities, and both *Verbal Reasoning Ability* and *Active Analysis* predicting *Achievement.* Model 2 includes *Verbal Reasoning Ability* and *Visual Synthesis* measured at baseline; both predict *Active Analysis* (Time 2), and *Achievement* (Time 3) regressed on *Verbal Reasoning Ability, Visual Synthesis,* and *Active Analysis* latent variables.

4. Results

Table 1 includes means and standard deviations for all manifest variables at each of the three time points. All values for skewness and kurtosis where within acceptable levels (Tabachnick & Fidell, 2007).

Table 1

Table of Descriptives for Independent and Dependent Variables

Descriptive Statistics

	N	Mean	Std. Deviation	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Age1	60	11.18	2.75	-0.11	0.31	-0.51	0.61
Age2	60	12.03	2.66	-0.06	0.31	-0.56	0.61
Age3	60	12.98	2.69	-0.03	0.31	-0.63	0.61
P1	60	2.40	0.76	-0.83	0.31	-0.77	0.61
P2	60	2.33	0.71	-0.58	0.31	-0.80	0.61
P3	60	2.18	0.70	-0.27	0.31	-0.91	0.61
MSC1	60	0.32	0.20	0.83	0.31	0.29	0.61
XoL1	60	0.42	0.16	0.06	0.31	-0.43	0.61
XoL2	60	0.53	0.17	-0.17	0.31	-0.35	0.61
XoL3	60	0.60	0.17	-0.08	0.31	-0.57	0.61
PU1	60	0.38	0.22	0.33	0.31	-0.34	0.61
AM1	60	0.39	0.14	-0.14	0.31	-0.27	0.61
CI1	60	0.38	0.15	-0.04	0.31	-0.46	0.61
CI2	60	0.44	0.17	-0.18	0.31	-0.91	0.61
AAbs1	60	0.74	0.22	-0.84	0.31	-0.23	0.61
AAan1	60	0.71	0.25	-0.70	0.31	-0.36	0.61
VP1	60	0.55	0.17	0.15	0.31	0.74	0.61
VP2	60	0.63	0.20	-0.27	0.31	-0.63	0.61
RFU1	60	0.40	0.19	-0.39	0.31	0.66	0.61
VL1	60	0.48	0.20	0.30	0.31	-0.42	0.61
VL2	60	0.55	0.18	-0.17	0.31	-0.89	0.61
SS1	60	0.40	0.20	0.70	0.31	0.26	0.61
SS2	60	0.63	0.18	-0.51	0.31	-0.01	0.61
VRA1	60	0.49	0.15	0.09	0.31	-0.03	0.61
VRA2	60	0.58	0.14	0.22	0.31	-0.17	0.61
VRA3	60	0.63	0.14	-0.13	0.31	-0.33	0.61
VS1	60	0.45	0.14	0.17	0.31	0.04	0.61
VS2	60	0.57	0.16	0.45	0.31	1.57	0.61
KmWk1	60	0.49	0.17	-0.23	0.31	0.14	0.61
KmWk2	60	0.56	0.16	-0.05	0.31	-0.28	0.61
KmWk3	60	0.63	0.15	-0.43	0.31	-0.42	0.61

Note: PU = paragraph understanding; MSC = Copying; AM = Short term auditory memory; RFU = Reading for Understanding; GAAan = Gibson Auditory Analysis (analysis); Cl = Closure Speed; VP = Gibson Visual Processing; VL = Gibson Logic and Reasoning; SS = Social Comprehension; XoL = GDRAAT Crossing-Out-Letters; KMWK= Achievement = the average of Woodcock and KeyMath percentages; VRA= Verbal Reasoning Abililty; VS= Visual Synthesis; Additionally, 1 = Baseline; 2 = End of Year 1; 3 = End of Year 2. PU = paragraph understanding; MSC = Copying; AM = Short term auditory memory; RFU = Reading for Understanding; GAAan = Gibson Auditory Analysis (analysis); Cl = Closure Speed; VP = Gibson Visual Processing; VL = Gibson Logic and Reasoning; SS = Social Comprehension; XoL = GDRAAT Crossing-Out-Letters; KMWK= Achievement = the average of Woodcock and KeyMath percentages; VRA= Verbal Reasoning Abililty; VS= Visual Synthesis; Additionally, 1 = Baseline; 2 = End of Year 1; 3 = End of Year 2.

4.1. Results from Structural Equation Modelling using longitudinal data

The original model based on cross-sectional data (Figure 1), demonstrated strong fit to the data with χ^2 (34) = 63.57, p = .00, CMIN/DF = 1.87, CFI = .97, RMSEA = .07 (Moxley-Paquette & Burkholder, 2014). The interactive model (Model 1) in which *Achievement* (Time 3) was regressed onto the three language components, *Verbal Reasoning Ability, Visual Synthesis, and Active Analysis* (all assessed at Time 1) demonstrated excellent fit to the data, χ^2 (42) = 48.37, p = .23, CMIN/DF = 1.15, CFI = .98, RMSEA = .05 . The hierarchical model (Model 2) in which the three components for language-based cognitive fitness; *Verbal Reasoning Ability, Visual Synthesis, and Active Analysis* with direct pathways to *Achievement* also demonstrated good model fit to the data (with the removal of the path from *Visual Synthesis* to *Achievement* due to its lack of statistical contribution to the model), χ^2 (50) = 63.00, p = .10, CMIN/DF = 1.26.

Table 2

Model Fit Criteria For Structural Equation Models

Models	χ^2	Df	p	CMIN/DF	CFI	RMSEA
Original Model Fit Results						
VRA1<->VS1; VRA1 <->AA1; VS1 <-> AA1 All 3F predict KMWK1	63.57	34	0.002	1.87	0.97	0.07
Model 1 - Interactive						
VRA1<->VS1; VRA1 <->AA1; VS1 <-> AA1 All 3F predict KMWK3	48.37	42	0.231	1.15	0.98	0.05
Model 2 - Hierarchical						
VRA1<->VS1; VRA1 -> AA2; VS1 -> AA2; VRA & AA predict KMWK3	58.25	46	0.106	1.27	0.97	0.07

Original model N=161; Longitudinal models N=60

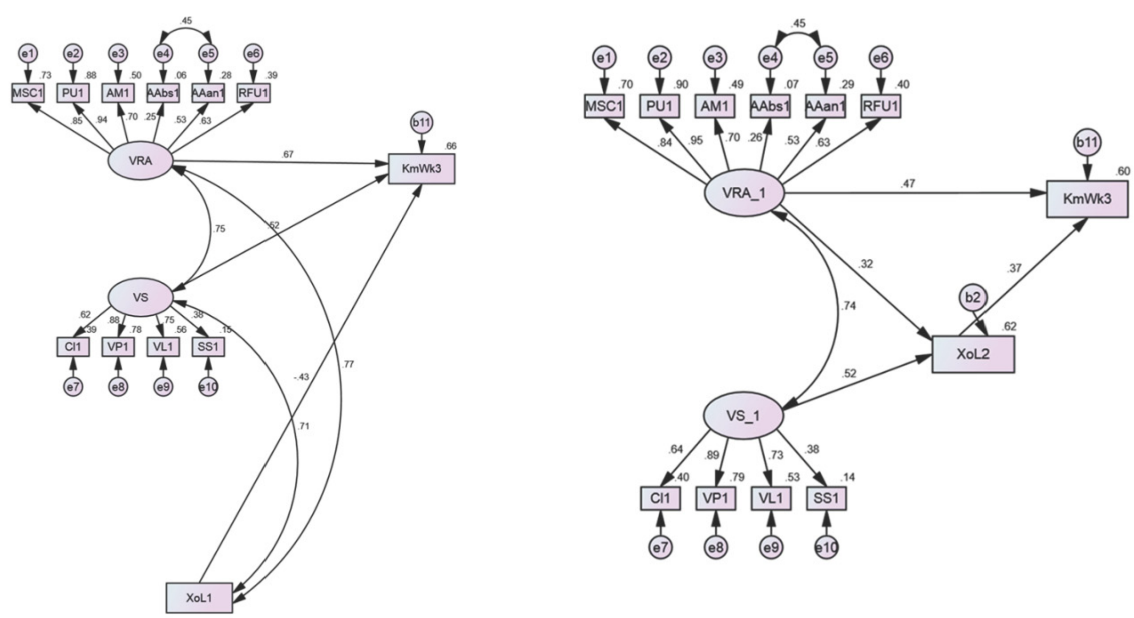
Note: KMWK= Achievement = the average of Woodcock and KeyMath percentages; VRA= Verbal Reasoning Abililty; VS= Visual Synthesis; AA=Active Analysis (equates to a single variable XoL); Additionally, 1 = Baseline; 2 = End of Year 1; 3 = End of Year 2.

Figure 2

Comparing Model 1 (Interactive) and Model 2 (Hierarchical)

Model 1 - Interactive

Model 2 - Hierarchical



Note: – the squares represent the 11 test items; the ovals represent the factors one and two with multiple variables; the rectangle represents factor three represented by one variable; the circles represent the error terms; the arcs represent covariances between variables and between factors; the arrows represent pathways of influence; and, the numbers over the pathways represent the strength of the path relationship. PU = paragraph understanding; MSC = Copying; AM = Short term auditory memory; RFU = Reading for Understanding; GAAan = Gibson Auditory Analysis (analysis); Cl = Closure Speed; VP = Gibson Visual Processing; VL = Gibson Logic and Reasoning; SS = Social Comprehension; XoL = GDRAAT Crossing-Out-Letters; Further note XoL = Active Analysis = AA. KMWK= Achievement = the average of Woodcock and KeyMath percentages; VRA= Verbal Reasoning Abililty; VS= Visual Synthesis; Additionally, 1 = Baseline; 2 = End of Year 1; 3 = End of Year 2.

In Model 1, In *Verbal Reasoning Ability* explained 67% (β =.67; p=.000) of the variance in *Achievement, Visual Synthesis* explained 52% (p<.01) of variance in *Achievement* and *Active Analysis* explained -43% (β =-.43; p<.01) of the variance in *Achievement*; all variables combined explained 66% of the variance in *Achievement*. Model 2, *Verbal Reasoning Ability* explained 47% (β =.47; p=.00) of the variance in *Achievement,* Visual Synthesis explained 52% (β =-.52; p<.01) of variance in *Active Analysis* and Active Analysis explained 37% (β =.37; p<.01) of the variance in *Achievement*; *Verbal Reasoning Ability* and *Active Analysis* latent variables explained 60% of the total variance in *Achievement*. *Verbal Reasoning Ability* (β =.32, p<.05) and *Visual Synthesis* (β =.52, p<.01) had an indirect effect on *Achievement* through *Active Analysis*.

5. Discussion

This analysis using longitudinal data was designed to test whether there is evidence to support the 3 factor language-based cognitive fitness model originally tested using cross-sectional data (Moxley-Paquette & Burkholder, 2014). Interactive and hierarchical longitudinal models fit the data well, supporting the study results of Moxley-Paquette and Burkholder (2014) and aspects of the theoretically offered hierarchical model (Moxley-Paquette, Burkholder, & Constantinidis, 2013. These results continue to support interplay among abilities (Buehner et al., 2005) and connectionism (each ability participating in multiple functions) rather than localizationism (Catani, 2009). Model 2 also suggests that a hierarchical structure is plausible, supporting the original formulation based on theory (Moxley-Paquette, Burkholder, & Constantinidis, 2013). Model 2 represents a variation of the original model in that *Verbal Reasoning Ability* and *Visual Synthesis* are covaried; this a limitation given that there were only three time points with data to ensure sufficient statistical power. However the interesting aspect of this model is the role of *Visual Synthesis* (VS1) as a mediator of their influence supporting both *Verbal Reasoning Ability* (VRA) as its covariate and *Active Analysis* (XoL) prediction of *Achievement*. *Visual Synthesis* does not directly influence *Achievement* in this model.

The evidence from this study also continues to support *Active Analysis* as a frontal lobe function (the ability to attend, discriminate, and supervise completion of a task). It is interesting that *Active Analysis* has both negative and positive relationships to *Achievement* depending on the model. In the interactive model (Model 1), *Active Analysis* is a self-monitoring ability that has a negative relationship with *Achievement*. This is consistent with research that has hypothesized that given we are measuring all 3 factors at the same time, there is a self-monitoring function that has the effect of detracting from achievement (Oberauer et al., 2003). This result is consistent with the original study (Moxley-Paquette & Burkholder, 2014). However, in the hierarchical model given we are not measuring all 3 factors at the same time, and *Active Analysis* is a channel for positively explaining variation in *Verbal Reasoning Ability* and *Visual Synthesis*, predicting *Achievement*. Active Analysis measured in time=2, fed by *Verbal Reasoning Ability* and *Visual Synthesis* in time=1, positively predicts *Achievement* in time=3. This too makes sense.

The results therefore provide both further model clarity and more questions. First, there is both interactive and hierarchical structure of language-based cognitive fitness using reading and mathematics achievement. Both the interactive and hierarchical language-based cognitive fitness models demonstrate research implications drawn from: MMN-vMMN (Garrido et al., 2009; Kujala et al., 2007); Näätänen, 2000; Näätänen, 2007); Näätänen et al., 2011; Pulvermüller et al., 2008; Pulvermüller & Shtyrov, 2003; Sussman, 2007; van Zuijen et al., 2006; Winkler & Czigler, 2011) for auditory and visual memory representations conjoining into object files (feature combinations) if they are matched within a temporal window, the interplay of cognitive abilities (Buehner et al., 2006), and functional language organization (Shalom & Poeppel, 2008).

6. Limitations, Next Steps, & Implications

There are several limitations of the study: It is assumed that instruments used in this study actually measure the underlying concept given the measures available for use but test measures can at best only approximately actual developmental functioning. It is possible that test measures validated with neuroimaging measurement techniques will be more able to accurately distinguish among the theoretical structures than what are currently available, exampled by sine-wave amplitudes for sounds used to assess speech discrimination and auditory-visual trace formation abilities as part of language-based cognitive testing protocols; this consistent with research methods used with infants as early as six months of age to identify risk for delayed language development (Kujala & Näätänen, 2001). Further the sample may not clearly represent the general population, since parents choose to have their children attend a private school. Children in the study had a higher percentage of challenged academic ability profiles (21%) than would be expected in the general population. However it is also possible that the range of abilities demonstrated in this study might be more reflective of the population of K-12 children in general if schools broadly conducted more extensive testing as completed by the private school involved in this study. In spite of the limitations, the research results provide insight into a model of language that can be further tested in other samples including those containing longitudinal data.

Finally, while we have enriched our insight into the structure of language-based cognitive fitness by demonstrating with longitudinal data that there is strong support for both interactive and hierarchical aspects to the development of language-based cognitive fitness there is further opportunity to elucidate the nature of these dynamics. Latent variable growth curve modelling (LVGC) using longitudinal data is a recommended next step for gaining insight into what may be happening specifically to *Achievement* over time. Cross-lagged panel analysis is recommended for gaining insight into the nature of the inner workings of each model. Finally, invariance analysis is recommended for looking at the models over time identifying which measures are the best and least stable measurement predictors. Hence while there is clarification, the plot thickens. This study has validated both interactive and hierarchical models but it still needs to be determined how the dynamics of each fit together.

Appendix A. An example appendix

Authors including an appendix section should do so before References section. Multiple appendices should all have headings in the style used above. They will automatically be ordered A, B, C etc.

A.1. Example of a sub-heading within an appendix

There is also the option to include a subheading within the Appendix if you wish.

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